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16. ABSTRACT The paper discusses on-line N2O measurements from six full-scale, coal-fired utility boilers that indicate direct N2O emissions of < 5 ppm. Laboratory and pilot-scale experiments conducted to further characterize direct N2O emissions are consistent with the field data indicating on-line N2O concentrations < 5 ppm. Further sub-scale coal experiments using air staging and natural gas reburning for NOx control show only slight increases in N2O emissions. These results question the reliability of the existing N2O data base, much of which is likely to be affected by a sampling artifact by which N2O can be produced in sample containers, awaiting analysis, through an as-yet-unknown mechanism possibly involving NO, SO2, and H2O. Time resolved measurements of N2O, NO, and SO2 from combustion emissions, collected in stainless steel sample containers, show that N2O concentrations in wet samples can increase to levels greater than 100 ppm in < 24 hours. These increases are reduced (but not eliminated) in dried samples. All samples show that NO reacts (possibly forming N2O) within 4 hours. SO2 concentrations decrease with time at rates related to the sample dryness. These results suggest the need for further research to identify other direct and indirect sources of N2O.

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N_2O EMISSIONS FROM FOSSIL FUEL COMBUSTION

W.P. Linak, J.A. McSorley, R.E. Hall
Combustion Research Branch, MD-65
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

J.V. Ryan, R.K. Srivastava
Acurex Corporation
4915 Prospectus Dr.
Durham, NC 27713

J.O.L. Wendt, J.B. Mereb
Department of Chemical Engineering
University of Arizona
Tucson, AZ 85721

ABSTRACT

On-line nitrous oxide (N_2O) measurements from six full-scale, coal-fired utility boilers indicate direct N_2O emissions of less than 5 ppm. Laboratory and pilot-scale experiments conducted to further characterize direct N_2O emissions are consistent with the field data indicating on-line N_2O concentrations below 5 ppm. Further sub-scale coal experiments using air staging and natural gas reburning for NO_x control show only slight increases in N_2O emissions. These results question the reliability of the existing N_2O data base, much of which is likely affected by a sampling artifact by which N_2O can be produced in sample containers, awaiting analysis, through an as-yet-unknown mechanism possibly involving NO, SO_2, and water. Time resolved measurements of N_2O, NO, and SO_2 from combustion emissions, collected in stainless steel sample containers, show that N_2O concentrations in wet samples can increase to levels greater than 100 ppm in less than 24 hours. These increases are reduced (but not eliminated) in dried samples. All samples show that NO reacts (possibly forming N_2O) within 4 hours. SO_2 concentrations decrease with time at rates related to the sample dryness. These results suggest the need for further research to identify other direct and indirect sources of N_2O.

INTRODUCTION

The atmospheric concentration of nitrous oxide (N_2O) is reported to be increasing at a rate of between 0.18 and 0.26 percent per year(1,2) from its present level of 303 ppb.(3) This is a matter of concern because N_2O has been implicated as both a "greenhouse" gas and a participant in stratospheric ozone depletion mechanisms. Fossil fuel combustion has been proposed as a possible major contributor to the measured increases in ambient N_2O concentrations, as these increases seem to track measured increases in ambient CO_2 concentrations. Additionally, limited data of direct N_2O emissions from fossil fuel

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combustion had indicated stack emissions exceeding 100 ppm, and an approximate average N_2O-N:NO_x molar ratio of 0.58:1.(3) These concerns, implications, and the limited data available prompted the U.S. Environmental Protection Agency (EPA) to stimulate collaborative national and international research programs with industry, academia, and other government agencies to better characterize the anthropogenic sources of N_2O. While partial summaries of these programs are presented elsewhere in the form of workshop proceedings(4,5), the purpose of this paper is to present the results of research and testing designed to characterize the direct N_2O emissions from stationary fossil fuel combustion. This research and testing was sponsored by the U.S. EPA through its Office of Policy, Planning, and Evaluation (OPPE) and Office of Air and Radiation (OAR), and was performed by EPA's Air and Energy Engineering Research Laboratory (AEERL). A portion of this work was sponsored by the U.S. Department of Energy (DOE).

Historical Data Base

A summary of the N_2O data base from stationary fossil fuel combustion as it existed following the second N_2O workshop, which was held in September 1987, is presented in Figure 1.(5) The open and half-filled symbols represent data from laboratory, pilot, and full-scale combustion systems taken by several research groups who first attempted N_2O measurement. Also included in Figure 1 is a line representing a proposed N_2O-N:NO_x molar ratio of 0.58:1.(3) The fully filled symbols represent data taken by our group using a laboratory-scale downfired coal combustor (2.3 kg/hr, 5 lb/hr) burning two western coals. These data (fully filled symbols), indicating direct N_2O emissions typically less tham 10 ppm, were presented but were not included in the workshop proceedings. At the time, these on-line gas chromatograph/electron capture detector (GC/ECD) data were considered suspect due to the limited number of data points, the untested sampling procedure, the poor condition of the analytical system, and the large discrepancies compared to the existing data base.

In an effort to improve the data quality, AEERL aquired a new dedicated GC/ECD system, set it up in a laboratory, and changed the sampling procedure to that used by several other research groups. This sampling procedure involved using stainless steel sampling containers and then scheduling the N_2O analyses. The results of these changes are presented in Figure 2. Again, fully filled symbols represent the data taken by this group burning the same two western coals, and are compared to the existing historical data (open and half-filled symbols). Variations in stoichiometry and burner swirl were used to affect NO_x (and possibly N_2O) concentrations. The new data were highly scattered, but agreed better with the existing data. These data were presented at the third N_2O workshop that was held in June 1988. At that meeting Muzio et al., conducting EPRI/EPA sponsored research, presented data suggesting the presence of an N_2O sampling artifact.(6) They presented evidence that indicated that N_2O might be produced in sampling containers awaiting analysis. They further hypothesized a mechanism of this formation involving NO, SO_2, and water. This evidence questioned the validity of all existing data which involved container sampling.

Based on this evidence, AEERL renewed efforts to characterize, by on-line means, the direct N_2O emissions from several laboratory and pilot-scale combustion systems burning a variety of coals, fuel oils, and natural gas. Additionally, we sought to compare the results from these sub-scale systems to direct N_2O measurements (by on-line techniques) from

full-scale pulverized-coal-fired utility boilers. Concurrent with all on-line analyses, we sought to characterize the time dependent evolution of N_2O, NO, and SO_2 in container samples.

ON-LINE MEASUREMENTS

Laboratory and Pilot-Scale Experiments

Three AEERL combustion systems that were used for the sub-scale experiments included a 29 kW (100,000 Btu/hr) refractory-lined, downfired, coal-fired tunnel combustor (Downfired Tunnel Furnace), a 733 kW (2,500,000 Btu/hr) gas/oil-fired, fire-tube package boiler (North American Boiler), and an 879 kW (3,000,000 Btu/hr) gas/oil-fired, water-tube package boiler simulator equipped with a low NO_x burner/precombustor (Low NO_x Burner/Package Boiler Simulator). Details regarding the specific designs of these systems have been presented elsewhere(7,8,9) and will not be reiterated here.

Although several analytical techniques in addition to GC/ECD are applicable to on-line N_2O analysis from combustion sources(4,6,10), most involve extractive sampling. The sampling system used at AEERL included extractive sampling through a stainless steel sampling probe, heated, 0.64 cm (0.25 in.) outside diameter (O.D.) Teflon tubing and particulate filter, water removal by use of a refrigeration drying system, and then pumping by means of a Teflon diaphragm sample pump through silica gel dessicant to continuous emission monitors (CEMs). CEMs included measurement of O_2, CO, CO_2, and NO. Immediately after the sample pump, a portion of the sample was directed to a 1 ml/six port GC sampling valve for on-line N_2O analysis by GC/ECD (Shimadzu Model GC-9A). SO_2 was measured from a heated sample taken downstream of the filter and upstream of the refrigeration dryer. The GC used to quantify N_2O utilized 5 percent methane in argon carrier gas at 20 cm^3/min., a 3.8 cm (1.5 in.) long by 0.64 cm (0.25 in.) O.D. P_2O_5 precolumn, a 3.66 m (12 ft) long by 0.32 cm (0.125 in.) O.D. stainless steel Poropak Super Q column at 35 °C, and a Ni^{63} ECD maintained at 330 °C.

Table 1 presents the combustion conditions and average on-line N_2O and CEM data for 10 AEERL tests involving the three combustion units and seven fuels including four types of coal. Evident from Table 1 is that the direct N_2O emissions from all tests never exceeded 5 ppm. In fact several natural gas and No. 2 fuel oil data indicate N_2O concentrations less than the instrument detection limit of 0.24 ppm. The coal tests showed the highest levels (2 to 4 ppm), and little difference could be discerned between the two fuel oil and natural gas tests. Data from the low NO_x burner/package boiler simulator, with and without air staging strategies for NO_x control, showed that, while significant NO reduction was seen with air staging, no measureable effect was detected in corresponding N_2O concentrations. These data, however, are too close to the instrument detection limit for accurate analysis. The other CEM measurements are comparable to those typical of full-scale units.

Experimental work on N_2O emissions from laboratory-scale coal combustors has also been completed at the University of Arizona (UA), under the sponsorship of the U.S. DOE. The downfired laboratory combustor used in that work was very similar in size and design to that described above for the AEERL tests, except that the pulverized coal flame was "premixed," and the overall configuration resembled a plug flow reactor. The flue gas

sample to be analyzed was withdrawn through a water cooled, water quenched probe. The water was removed in a refrigerated knockout pot, and the sample was passed through a 1 ml gas sampling valve into a Shimadzu Model GC-8A GC equipped with a 3.66 m (12 ft) long, 0.32 cm (0.125 in.) O.D. stainless steel column packed with Porapak Q, conditioned at 220 °C. An ECD, operating at 250 °C, required the use of argon with 5.22 percent methane as the carrier gas. Complete details of the sampling and analysis procedure can be found elsewhere.(11) Table 1 also presents four data sets from the University of Arizona work, representing exhaust conditions under baseline, air staging, and natural gas reburning conditions for a Utah bituminous coal. These data are consistent with the on-line AEERL data.

Figure 3 shows values of exhaust NO and N_2O emissions as a function of stoichiometric ratio for a Utah bituminous coal. N_2O levels vary from 0.5 to 1.5 ppm. Time resolved profiles during air staging are shown on Figures 3b (primary SR=0.86) and 3c (primary SR=0.65), and demonstrate the interesting fact that staging causes an increase in N_2O near the staging point. However, N_2O levels are still exceedingly low and so the effect is not of practical significance. Figure 3d shows time resolved NO and N_2O profiles along the combustor axis during employment of reburning as a NO_x control technique. We observed an increase of N_2O at the point of air injection, similar to what was observed under air staged conditions. For all configurations, however, these on-line measurements of N_2O yielded extremely low values, and indicated that direct N_2O emissions did not appear large from pulverized coal combustion, either with or without combustion modifications for NO_x control.

Field Tests

Following the laboratory and pilot-scale experiments, AEERL sponsored a field study to characterize the direct emissions of N_2O from full-scale, coal-fired utility boilers. These measurements were conducted by Acurex Corporation at six boilers ranging in size from 165 to 700 MW, including Circular, Triple Cell, and Tangential designs manufactured by Babcock & Wilcox, Riley Stoker, and Combustion Engineering. These units burned primarily a medium sulfur Alabama bituminous coal. The sulfur content of this coal is reported to be in the range of 1.5 to 2.0 percent. The sampling and analytical methods used were similar to those described above for the AEERL sub-scale experiments. Table 2 presents the average on-line N_2O and CEM data for each of the six utility units. All on-line N_2O measurements were below 5 ppm. In fact, almost all of the on-line N_2O measurements were below the detection limits of the two GC/ECD systems used (1.2 and 3.6 ppm). These samples were taken at existing sampling locations, downstream of all economizer and particulate removal equipment, either before or after the systems' induced draft fan. All six units were operated at or near full load during the tests. Limited SO_2 data were collected due to problems with the SO_2 analyzer.

A summary of the on-line data from both the sub-scale and full-scale studies is presented in Figure 4. Again, these data (indicated by the fully filled symbols) are compared to the previous data base (open and half-filled symbols). These results suggest that the direct emission of N_2O from coal-fired utility boilers is likely low (less than 5 ppm), that the existing data are suspect due to an as-yet-undefined sampling artifact, and that no simple N_2O/NO_x correlation exists. The data do not indicate, however, that other types of

combustion sources are not major N_2O emitters, or that indirect mechanisms of atmospheric N_2O formation from combustion emissions do not exist.

TIME RESOLVED MEASUREMENTS FROM SAMPLE CONTAINERS

Concurrent with all on-line activities, extracted samples were collected in stainless steel sampling containers for time dependent analyses of N_2O by GC/ECD, NO by GC/thermal conductivity detector (TCD), and SO_2 by GC/flame photometric detector (FPD) techniques. These samples were collected at three degrees of dryness including wet samples (before refrigeration dryer), partially dried samples (immediately after refrigeration system), and dessicated samples (after additional drying by use of a P_2O_5 filled canister). Samples from the sub-scale experiments were analyzed at 1, 4, 24, 48, 168, and 336 hours. Samples from the full-scale tests were analyzed at 1, 4, 48, 168, and 336 hours. Time-resolved NO measurements were not taken for the full-scale tests due to limited availability of field equipment. Additionally, limited time resolved SO_2 data were produced from the full-scale tests due to instrument problems in the field.

Samples for time resolved analyses were collected in 0.5 L stainless steel containers. These containers were fitted with septums for sample extraction by gas syringe. A number of samples were collected in glass containers of similar size for comparison. While the available data for this comparison are very limited, they indicate similar sample evolution trends in each type of container. However, the rate of N_2O increase may be somewhat lower in glass containers. Combustion gas and N_2O calibration gas (10 ppm) samples of varying moisture content were passed through beds of different desiccants and analyzed to determine any effect of selective water removal on N_2O. Three desiccants were tested including phosphorus pentoxide (P_2O_5), magnesium perchlorate [$Mg(ClO_4)_2$], and silica gel (SiO_2). None of these desiccants was seen to affect the N_2O concentration. P_2O_5 was chosen as the desiccant of choice for these tests due to its almost quantitative ability to remove water. Tests were also conducted to identify sorbents for the selective removal of SO_2 from the extracted gas samples. Sodium hydroxide (NaOH) and calcium hydroxide (CaOH) have been examined as possible candidates. The data presented here, however, do not include any sample processing for SO_2 removal.

Figures 5 through 8 present the results of these time resolved analyses. In an effort to conserve space, only selected data (indicative of general trends) will be presented. Figures 5a and 5b present the evolution of N_2O and SO_2 from samples taken during the Utah bituminous laboratory-scale coal experiments. Figure 5c presents similar N_2O evolution data for the full-scale coal-fired utility boiler tests from unit D. It is interesting to note that both the sub-scale and full-scale N_2O data from wet or partially dry samples show rapid increases in the first minutes and hours after sampling. Smaller (but non-negligible) increases are seen in the dry samples. Maximum N_2O values from wet samples are seen after 24 hours. These values (200 and 75 ppm) are comparable to those presented by the historical data and the proposed N_2O-N:NO_x correlation (Figure 1). The maximum N_2O concentration is likely related to the initial NO and SO_2 concentrations. This speculation is supported by comparing the N_2O and initial NO data from these two tests. Figure 5 shows the N_2O concentrations in the wet and partially dry samples to slowly decrease after 24 to 48 hours. This reduction, however, may be due to slight air leaks into the sample containers due to numerous septum punctures and the volume of sample removed. Steps were taken in later data collection activities to limit the number of samples taken from

each container and increase the number of containers used. Figure 5b shows that the evolution of SO_2 seems to be very much dependent on the sample dryness. These data are presented out to 168 hours to increase the resolution at the lower times. NO data (not presented) all show rapid removal/reaction (possibly forming NO_2) within 1 to 4 hours regardless of the moisture content of the samples.

Figures 6 and 7 present similar data for No. 5 and No. 2 fuel oils, respectively, from the two smaller-scale combustion systems. Similar behavior, as compared with the coal data, is evident with respect to both N_2O and SO_2. Again, NO was removed/reacted to below detectable levels within 1 to 4 hours. It is interesting to note that, while the trends are similar to those seen for coal, the magnitude of the artifact is much less for the two fuel oils. The data presented are also consistent with the supposition that the resulting N_2O formation is dependent on the initial NO and SO_2 levels (in addition to the moisture). Note that N_2O increases seen in the Package Boiler Simulator samples (where NO_x control was used) are significantly smaller than those seen in the North American Boiler samples (without NO_x control) burning the same fuels.

The evolution of N_2O from samples from these same two units burning natural gas is presented in Figure 8. SO_2 emissions were for the most part below detectable levels. And again, NO was removed from all samples within 1 hour. The N_2O data are inconclusive. Some of the data suggest that the artifact still exists at minimal SO_2 levels, while other data show this effect to be negligible. Further samples from natural gas flames are planned to investigate this further.

CONCLUSIONS

Results from on-line (GC/ECD) N_2O measurements from six full-scale utility boilers burning a medium sulfur Alabama bituminous coal indicate direct N_2O emissions of less than 5 ppm. Additional results from laboratory and pilot-scale combustion experiments using similar procedures and burning a variety of coals, fuel oils, and natural gas are consistent with these full-scale N_2O data. Further experiments using a laboratory-scale coal combustor indicate that combustion modifications used for NO_x control may cause slight increases in N_2O emissions. These increases, however, are minor, causing overall increases of less than 5 ppm. These results question the reliability of the existing historical data base, much of which is likely affected by a sampling artifact. These historical data had indicated direct N_2O emissions exceeding 100 ppm. Additionally, these past data had suggested a linear N_2O-N:NO_x molar ratio of approximately 0.58:1.

Time resolved analyses of samples collected in stainless steel containers suggest that N_2O can be produced in the sample awaiting analysis within minutes. While the mechanism of this formation is unknown, it seems directly dependent on the initial concentrations of water, SO_2, and NO in the sample. This artifact can be reduced (but not eliminated) by removing the moisture present in the sample by desiccation. Characterization of full-scale combustion emissions in the field by container sampling is much more cost effective compared to on-line analyses. Hence, efforts are continuing to examine techniques for the selective removal of SO_2 in order to minimize the effects of the artifact in container samples.

The data indicate that the direct emission of N_2O from pulverized-coal-fired utility boilers is likely to be low (< 5 ppm). The data, however, do not support the conclusion that other types of combustion sources are not major N_2O emitters, nor do the data indicate that indirect mechanisms of atmospheric N_2O formation involving the constituents of combustion emissions do not exist. Identification of the mechanisms involved with the sampling artifact may shed some light as to whether similar mechanisms could exist in the atmosphere.

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DISCLAIMER

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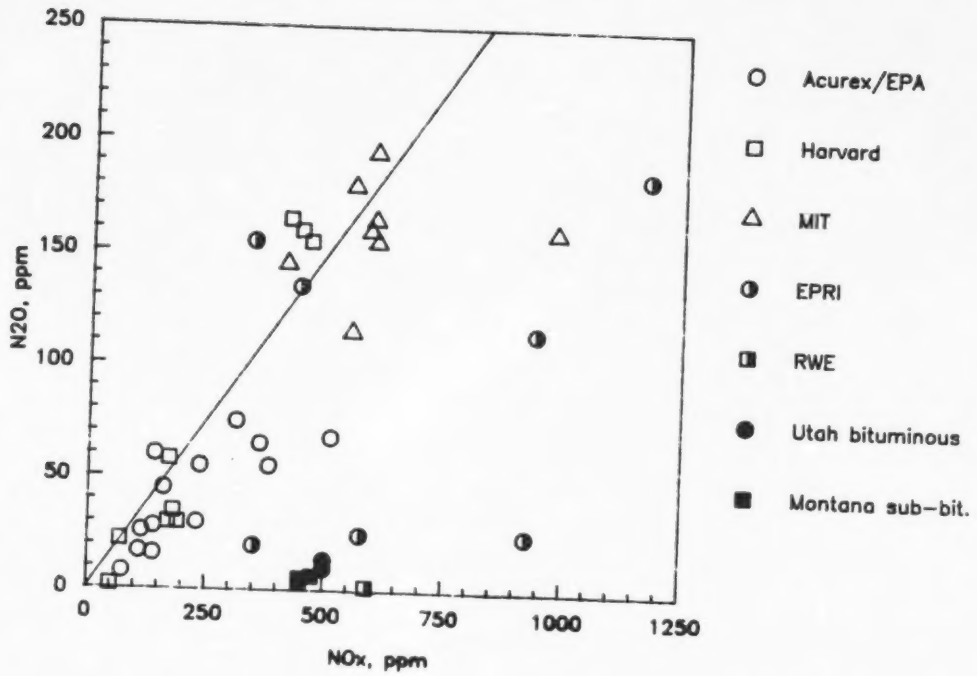

Figure 1. Existing N_2O/NO_x data from laboratory, pilot, and full-scale combustion systems presented at the EPA/NOAA/NASA/USDA N_2O Workshop.(5) Open and half-filled symbols represent historical data. The N_2O-N:NO_x correlation of Hao et al. (3) is presented. Fully filled symbols represent data taken by this group (and presented at the Workshop) burning two coals in a laboratory-scale combustor using an on-line GC/ECD sampling/analysis technique.

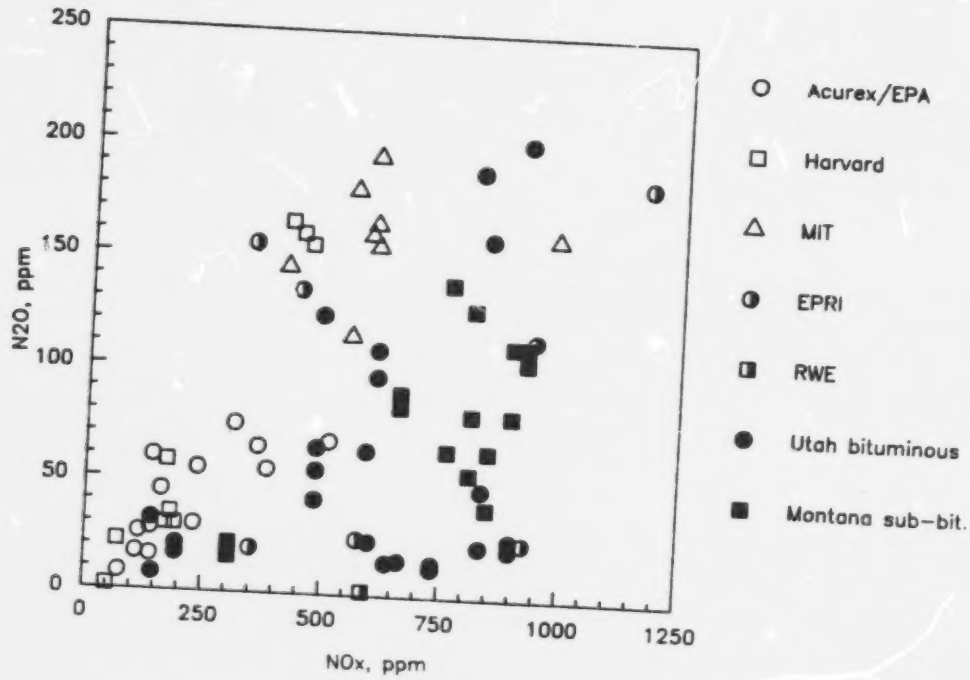

Figure 2. Existing N_2O/NO_x data as presented in Figure 1, compared to data taken by this group using an off-line sampling technique. Open and half-filled symbols represent historical data. Fully filled symbols represent data taken by this group burning the same two coals in the same combustor as presented in Figure 1 but using an off-line container sampling technique (refrigeration drying) with subsequent GC/ECD analysis.

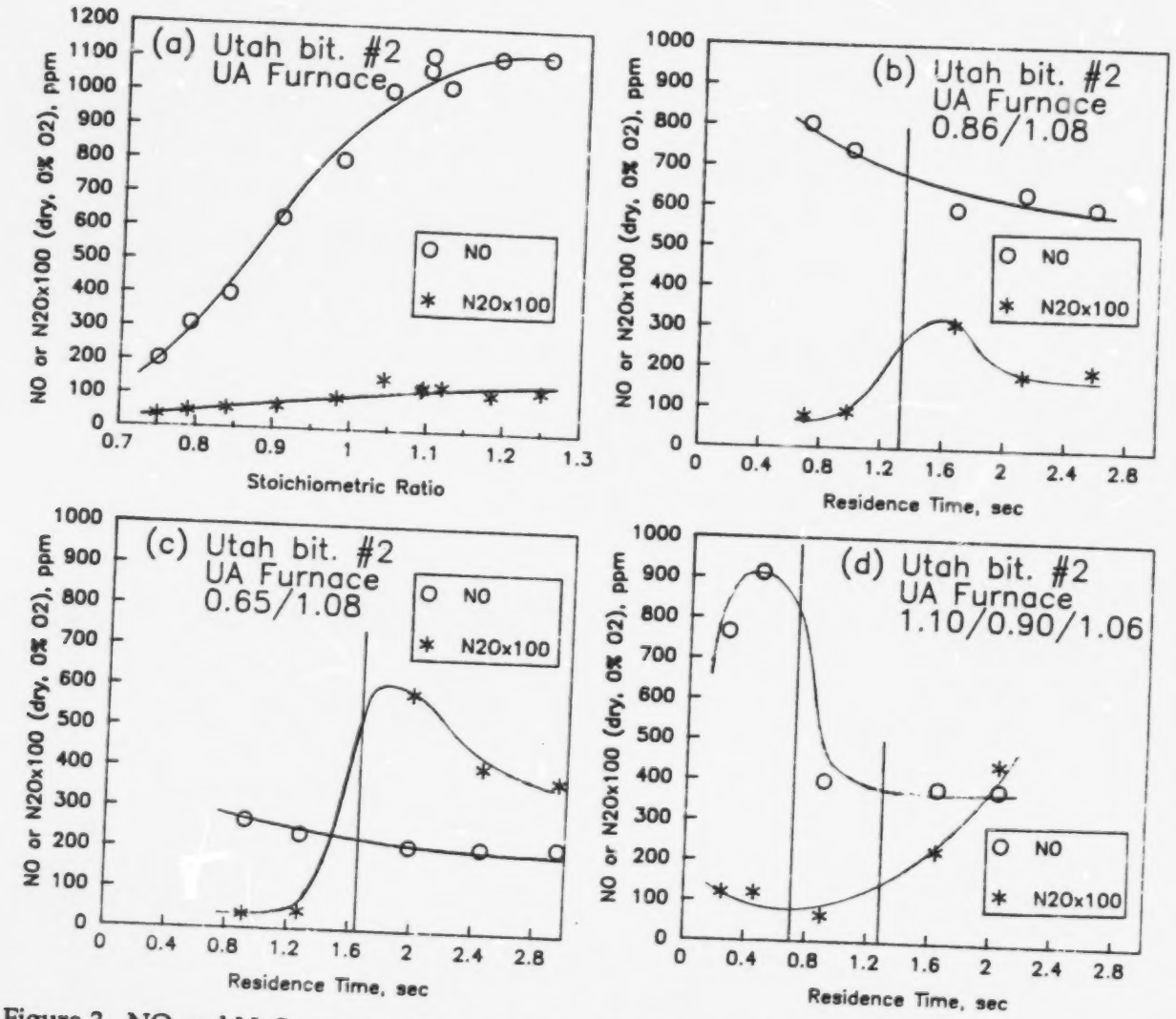

Figure 3. NO and N_2O concentrations from a laboratory-scale coal combustor as a function of (a) stoichiometric ratio (at combustor exhaust), and residence time using air staging (b) SR=0.86/1.08, (c) SR=0.65/1.08, and natural gas reburning (d) SR=1.10/0.90/1.06 strategies for NO_x control.

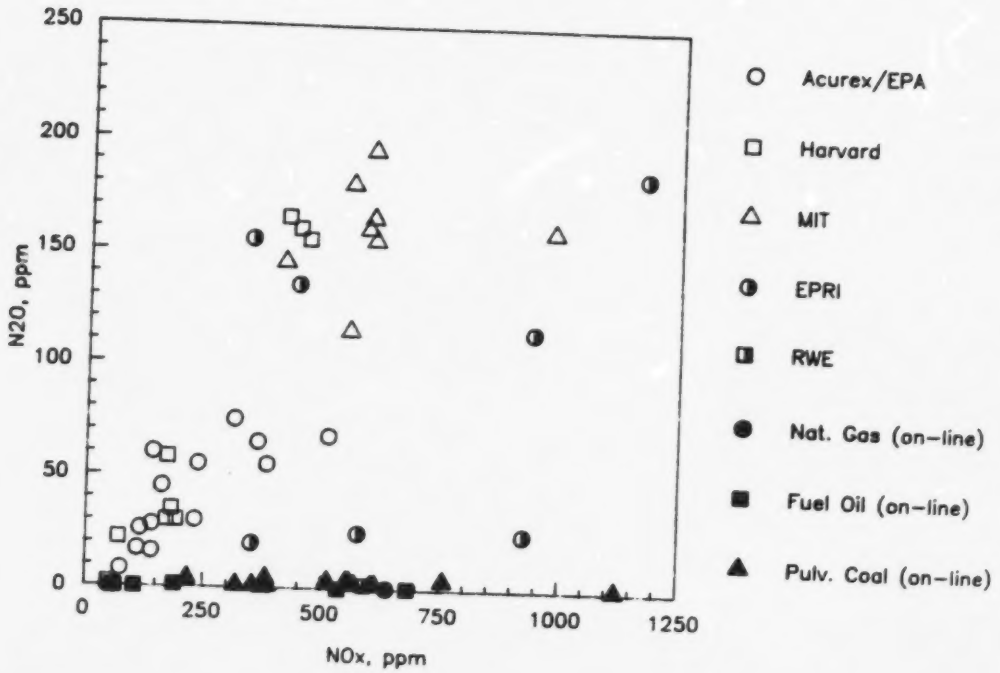

Figure 4. Existing N_2O/NO_x data as presented in Figures 1 and 2, compared to on-line data taken by this group. Open and half-filled symbols represent historical data. Fully filled symbols represent data taken by this group from full and sub-scale combustion systems burning several types of coals, fuel oils, and natural gas using an on-line GC/ECD sampling/analysis technique.

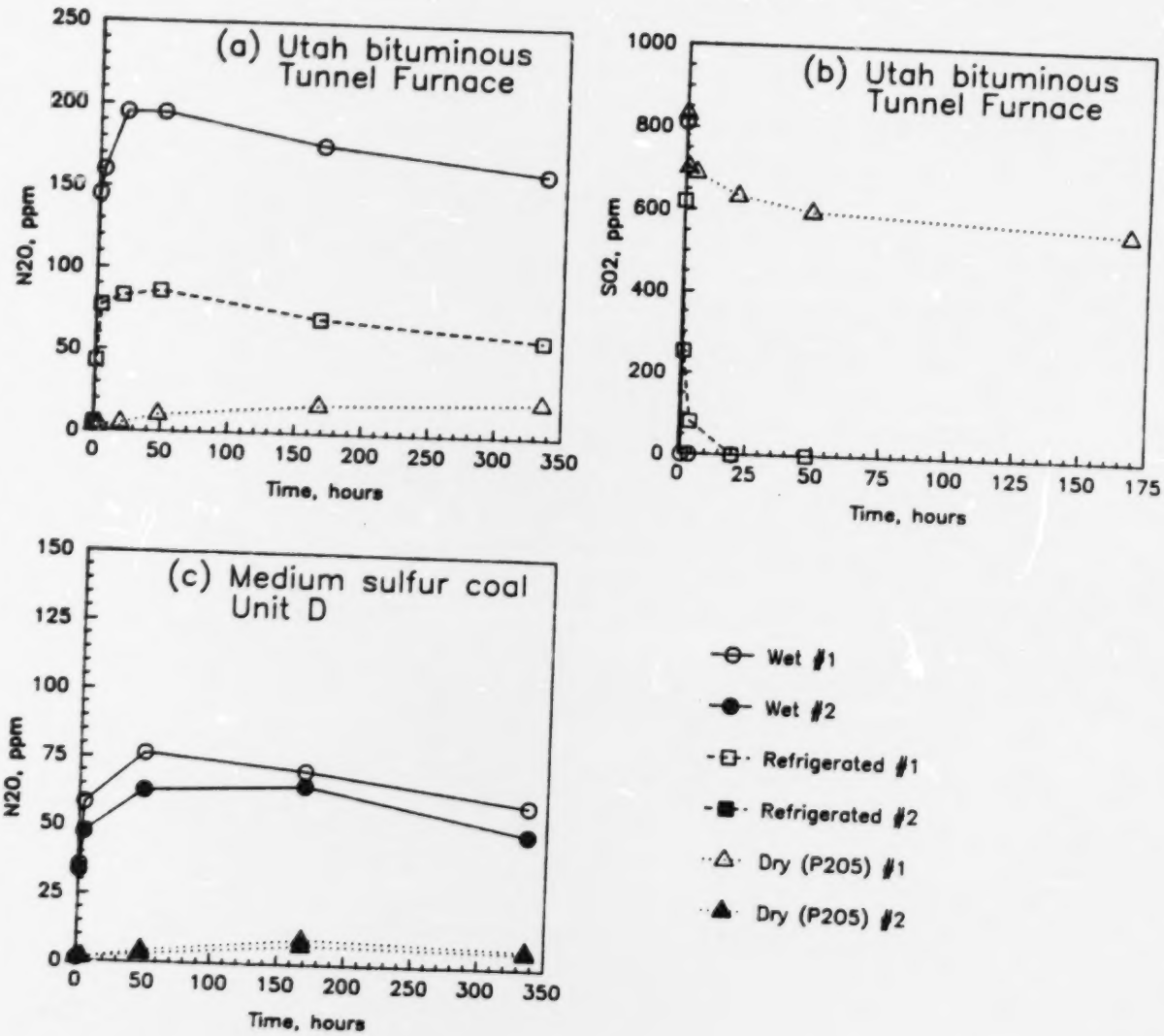

Figure 5. Evolution of N_2O and SO_2 with time from coal combustion samples collected and stored in stainless steel sampling containers at three degrees of sample dryness. Stack emission samples were collected using the (a, b) Downfired Tunnel Furnace burning Utah bituminous coal (SR = 1.42), NO(initial) = 757 ppm, and (c) Unit D (full-scale utility boiler) burning medium sulfur Alabama bituminous coal, NO(initial) = 354 ppm.

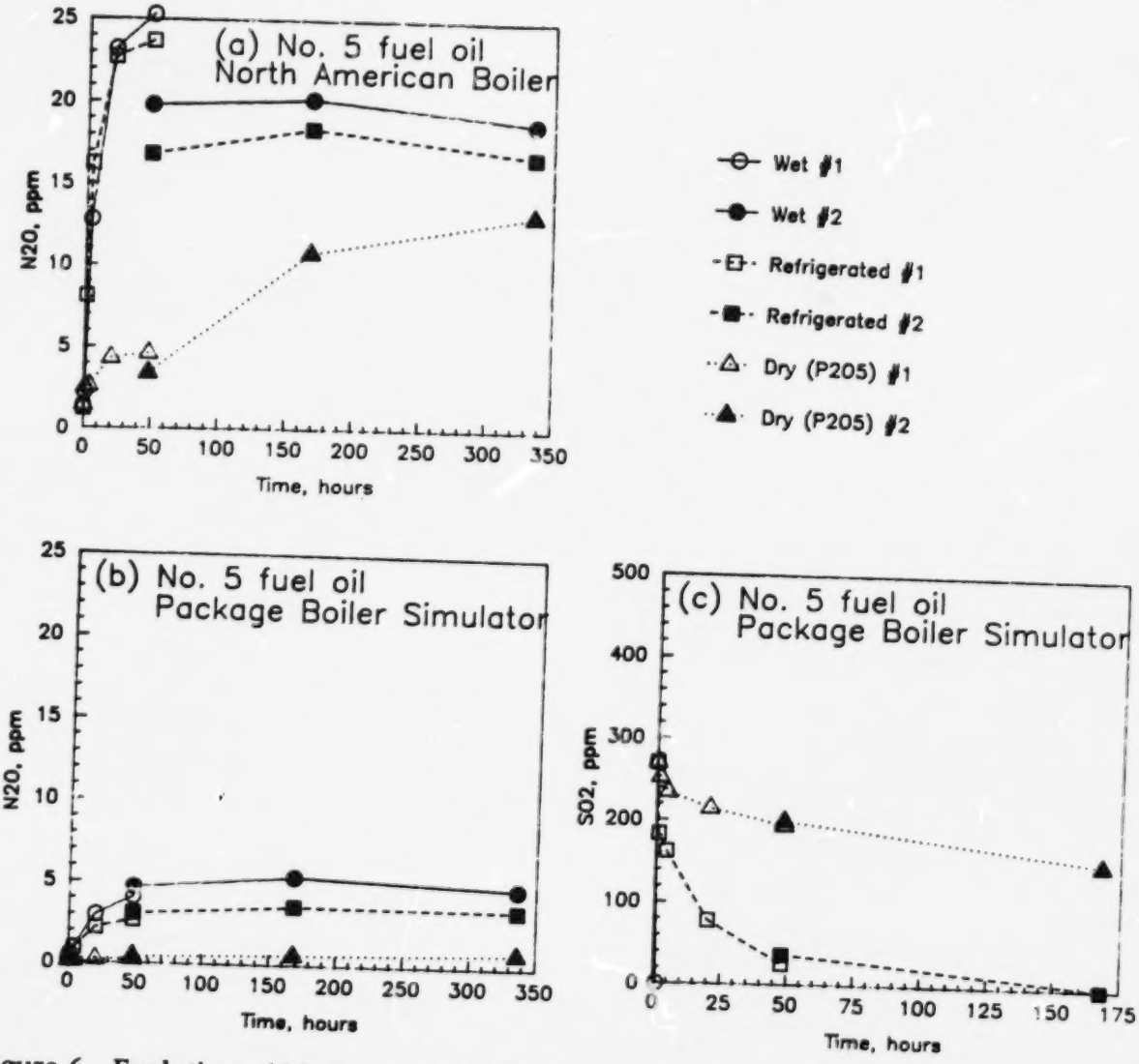

Figure 6. Evolution of N_2O and SO_2 with time from No. 5 fuel oil combustion samples collected and stored in stainless steel sampling containers at three degrees of sample dryness. Stack emission samples were collected using the (a) North American Boiler burning No. 5 fuel oil (SR = 1.25), NO(initial) = 189 ppm, and (b, c) Low NO_x Burner/Package Boiler Simulator burning No. 5 fuel oil (SR = 0.66/1.29), NO(initial) = 60 ppm.

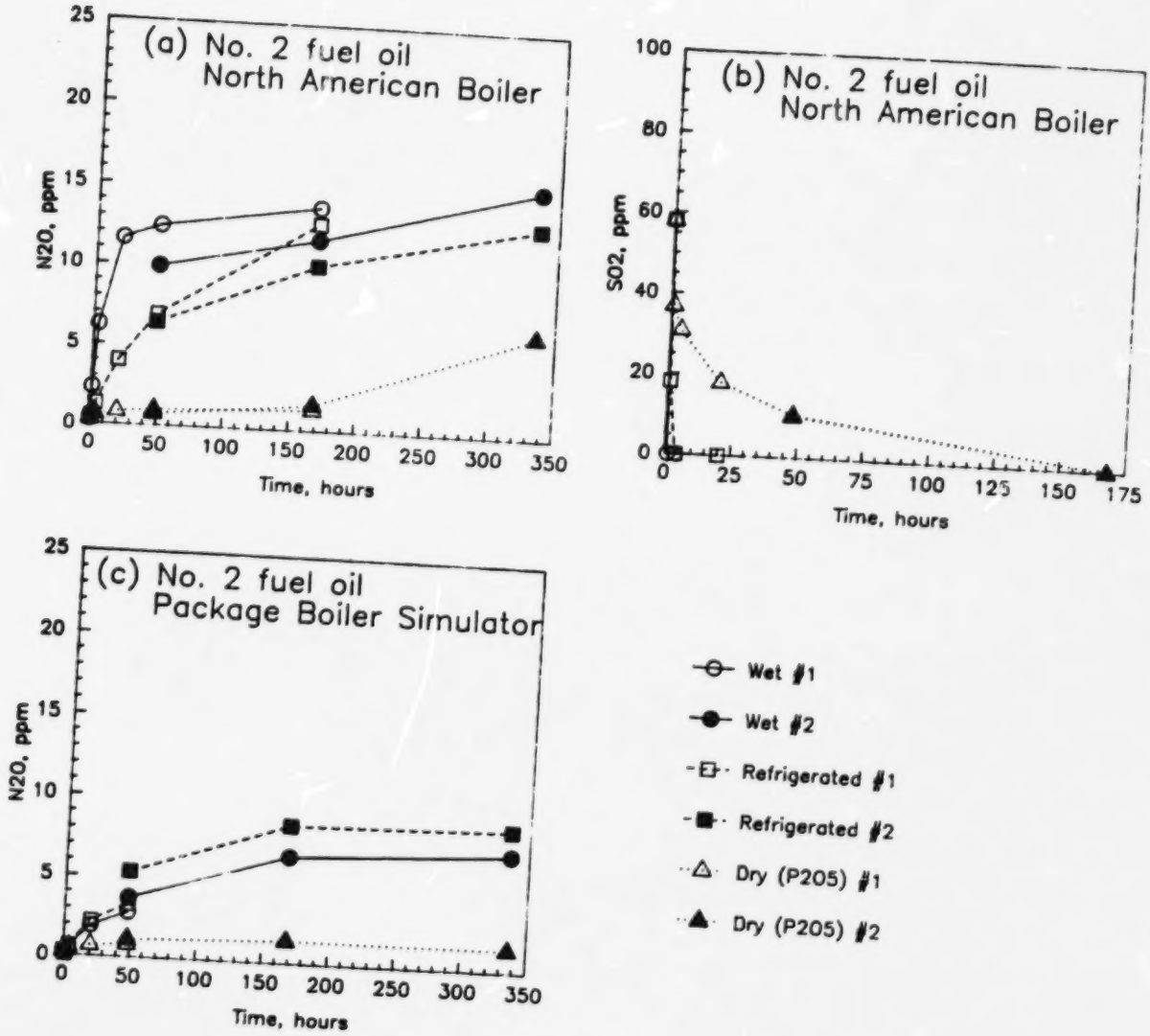

Figure 7. Evolution of N_2O and SO_2 with time from No. 2 fuel oil combustion samples collected and stored in stainless steel sampling containers at three degrees of sample dryness. Stack emission samples were collected using the (a, b) North American Boiler burning No. 2 fuel oil (SR = 1.25), NO(initial) = 105 ppm, and (c) Low NO_x Burner/Package Boiler Simulator burning No. 2 fuel oil (SR = 0.65/1.26), NO(initial) = 64 ppm.

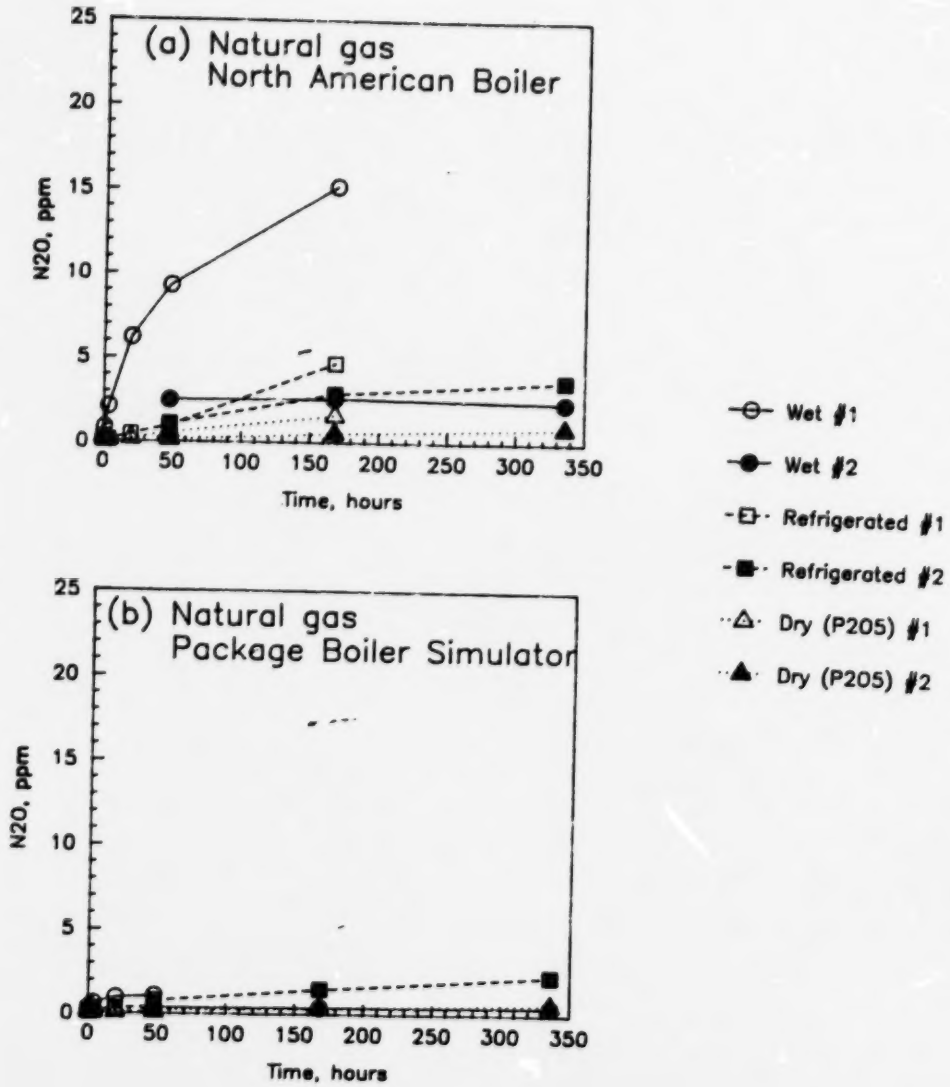

Figure 8. Evolution of N_2O and SO_2 with time from natural gas combustion samples collected and stored in stainless steel sampling containers at three degrees of sample dryness. Stack emission samples were collected using the (a) North American Boiler burning natural gas (SR = 1.24), NO(initial) = 62 ppm, and (b) Low NO_x Burner/Package Boiler Simulator burning natural gas (SR = 0.73/1.25), NO(initial) = 50 ppm.

Table 1

AVERAGE ON-LINE CONCENTRATIONS TAKEN FROM LABORATORY AND PILOT-SCALE COMBUSTION SYSTEMS*

Unit	Fuel	SR**	N_2O ppm	NO ppm	SO_2 ppm	CO ppm	O_2 %	CO_2 %
Tunnel Furnace	Utah bit. coal	1.42	4.2	757	753	17	5.5	13.9
Tunnel Furnace	Montana sub-bit. coal	1.43	2.2	613	380	30	5.3	14.6
Tunnel Furnace	Western Kentucky bit. coal	1.46	3.7	553	1650	12	6.8	12.6
Tunnel Furnace	Pittsburgh bit. coal	1.33	2.2	570	1450	-***	5.7	12.9
N. Amer. Boiler	Natural gas	1.24	<0.24	62	0	0	4.4	8.9
N. Amer. Boiler	No. 2 fuel oil	1.25	0.30	105	58	3	4.4	12.3
N. Amer. Boiler	No. 5 fuel oil	1.25	1.3	189	236	16	4.4	14.1
Low NO_x Burner/PBS****	Natural gas	0.73/1.25 1.10/1.25	<0.24 0.72	50 638	6 4	11 14	4.6 4.6	9.2 8.7
Low NO_x Burner/PBS	No. 2 fuel oil	0.65/1.26 1.13/1.26	<0.24 0.27	64 536	130 130	2 2	6.1 6.0	12.0 12.0
Low NO_x Burner/PBS	No. 5 fuel oil	0.66/1.29 1.10/1.18	0.26 0.73	60 682	270 270	25 25	5.4 4.1	12.2 11.0
UA Coal***** Furnace	Utah bit. coal	1.25	1.28	1121	-	300	4.25	14.0
UA Coal Furnace	Utah bit. coal	0.65/1.08	1.99	605	-	400	3.60	14.3
UA Coal Furnace	Utah bit coal	0.86/1.08	3.80	216	-	500	3.50	14.8
UA Coal Furnace	Utah bit. coal	1.10/0.90 /1.06	4.45	382	-	400	3.85	13.8

*All concentrations presented as measured (dry), no correction to constant percent O_2.
**Stoichiometric ratio.
***Missing data.
****Package Boiler Simulator.
*****UA data corrected to 0 percent O_2 (dry).

Table 2

AVERAGE ON-LINE CONCENTRATIONS TAKEN FROM FULL-SCALE UTILITY BOILERS*

Unit	Size MW	Class/Type**	N_2O ppm	NO ppm	SO_2 ppm	CO ppm	O_2 %	CO_2 %
A	250	Pre-NSPS Circular Babcock & Wilcox	1.3	386	-***	-	4.6	14.8
B	250	Pre-NSPS Triple Cell Babcock & Wilcox	<3.6	513	-	13.3	7.1	13.5
C	250	Pre-NSPS Circular Riley Stoker	<3.6	559	-	8.6	6.1	14.3
D	165	Pre-NSPS Tangential Combustion Engineering	<1.2	354	-	2.2	8.3	11.7
E	700	Pre-NSPS Tangential Combustion Engineering	0.7	374	-	30.7****	6.0	13.1
F	165	Pre-NSPS Tangential Combustion Engineering	<1.2	319	930	3.1	8.1	11.9

*All concentrations presented as measured (dry), no correction to constant percent O_2.
**All units burned a medium-sulfur Alabama bituminous coal.
***Missing data.
****CO trace showed numerous spikes.